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Past attempts to provide arm flair protection for USAF emergency ejection seats have not been successful. The devices that have been designed have ranged from mechanically deployed web nets to paddles which retain the arms during the ejection sequence. Although each system has had advantages, factors such as mechanical complexity, lack of crew acceptance, weight, space limitations, and dependence on directional stability of the ejection seat have precluded their acceptance or operational effectiveness.

To overcome these factors, the authors designed and tested an active limb restraint system that can be used in current and future escape systems. This system, referred to as the Nonrestrictive Arm Restraint (NAR), is a sleeve-mounted strap configuration, as shown in Figure 1. It is attached to the seat by straps which are routed through snubbers to a shear pin on the aircraft floor. Seat motion up the ejection rails activates the system, simultaneously pulling the elbows of the crewmember to his torso and his wrists to the ejection controls. The crewmember is restrained in this position until released at seat/man separation.

A Laboratory test program was conducted to evaluate the effectiveness of the design. The tests included emergency ground egress, seat/man separation, windblast, and upper limb capture and haulback.

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DEVELOPEMENT AND EVALUATION OF A DEVICE FOR THE PREVENTION OF ARM FLAIL INJURIES

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INTRODUCTION. Past attempts to provide arm flail protection for USAF emergency ejection seats have not been successful. The devices that have been designed have ranged from mechanically deployed web nets to paddles which retain the arms during the ejection sequence. Although each system has had advantages, factors such as mechanical complexity, lack of crew acceptance, weight, space limitations, and dependence on directional stability of the ejection seat have precluded their acceptance or operational effectiveness.

To overcome these factors, the authors designed and tested an active limb restraint system that can be used in current and future escape systems. This system, referred to as the Nonrestrictive Arm Restraint (NAR), is a sleeve-mounted strap configuration, as shown in Figure 1. It is attached to the seat by straps which are routed through snubbers to a shear pin on the aircraft floor. Seat motion up the ejection rails activates the system, simultaneously pulling the elbows of the crewmember to his torso and his wrists to the ejection controls. The crewmember is restrained in this position until released at seat/man separation.

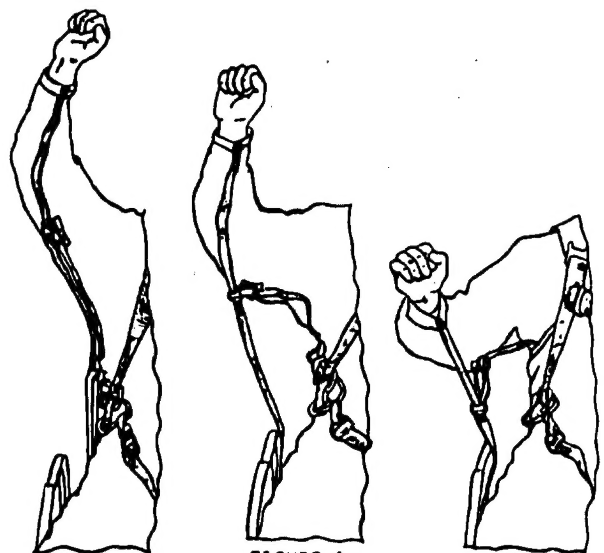

FIGURE 1.

A Laboratory test program was conducted to evaluate the effectiveness of the design. The tests included emergency ground egress, seat/man separation, windblast, and upper limb capture and haulback.

METHODS. An F-4 egress trainer was used to evaluate emergency egress. During these tests a crewmember performed normal pre-flight hookup, with the additional task of routing retraction straps through rings on the arm restraint and into lock-pin boxes on the ejection seat. This action was performed to engage the NAR. Emergency egress was then executed without deviating from established emergency egress procedures.

Seat/man separation during escape was also simulated using the F-4 egress trainer. All restraint systems, including the NAR, were cinched tightly to simulate the crewmember's positioning in the airstream. An observer activated the emergency release handle to simulate the operation of the automatic recovery sequence thruster that releases the crewmember's restraint system during seat/man separation. The subject was then hoisted from the seat to simulate separation.

The windblast tests were conducted at the Dayton T. Brown Windblast Facility using a 95th percentile dummy seated in an ACES II ejection seat. Controlled release of stored, compressed air simulated the windblast environment. It was planned to test the NAR at airspeeds of 309 ± 10 m/s (600 ± 20 KEAS) for a minimum of 0.3 seconds. Seven seat attitudes were to be used. Arm restraint loads were measured at the seat connections and windblast velocities were recorded.

Arm capture and haulback tests were accomplished using the AFAMRL Body Positioning and Restraint Device (BPRD) with volunteer subjects and anthropomorphic dummies. The BPRD is a hydraulically actuated retraction system used to evaluate restraint and positioning systems. Retraction force was applied to the NAR by cables routed through a series of pulleys to the hydraulic actuators of the BPRD. Retraction strap velocities were increased by raising the hydraulic pressure. Load cells mounted in line with the cable measured the retraction strap forces. High speed and video cameras recorded each test for photometric evaluation. Retraction velocities were gradually increased to levels approaching expected operational strap retraction velocities which have been estimated to be 9.3 m/s.

Twenty-one volunteer subjects, twenty male and one female, participated in the haulback test program. Their arm lengths measured from the wrist (stylion) to the shoulder (acromion) varied from 0.54 m to 0.68 m with a mean of 0.61 m.

Five different initial arm positions were evaluated. These were the "D-Ring" position, where the subject placed both hands on the ejection control; the "Front" position, with both arms placed directly in front of the subject; the "Side" posi-

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tion, with the arms held horizontal to the subject's sides; and the "Above" position with the arms positioned above the subject's head; and the "Across" position, with one arm extended across the chest. The position of the subject's hands after retraction were at the D-Ring initiation control. Retraction to the D-Ring was chosen rather than the side arm control position because (1) it was viewed more difficult to retract the NAR in this configuration, and (2) it was viewed as a less stressful environment for the subject. The initial arm positions were chosen to represent the extreme arm placements that might occur in multicrew aircraft should an aircrewmember be ejected unaware. Each subject wore thick work gloves and ensolite padding on the thighs and forearms for protection.

RESULTS AND DISCUSSION. The emergency egress and seat/man separation tests demonstrated minimal ingress tasks, positive release during seat/man separation, and unimpeded egress from the aircraft. These tests also demonstrated unrestricted crewmember mobility and the ease of integrating the NAR with an existing ejection seat.

Eight windblast tests were performed. All tests except test 8 were accomplished with an ejection rail angle of 0.3 rad (17°). The yaw angle was 0 rad (0°) except in test 6 where a 0.79 rad (45°) yaw angle was used. Failure of the NAR sleeves due to inadequate seam strength was the primary defect demonstrated by these tests. Both sleeves failed in tests 1, 3, and 4 at windstream velocities ranging from 345 to 371 m/s (670 to 720 knots). No failures were observed in test 2 at 311 m/s (605 knots), but the duration of the windblast exposure did not meet the minimum time requirement. The NAR successfully withstood windstream velocities of 346 m/s (672 knots) and 349 m/s (677 knots) in tests 5 and 7 respectively. The straps of the inertia reel failed during test 6 at 349 m/s (677 knots). During test 8, where the seat was pitched 0.31 rad (18°) forward, the stitches on the upper part of the right sleeve failed when exposed to a windblast velocity of 344 m/s (668 knots). The maximum strap force measured was 4072 N (911 lbs) which occurred during test 8.

The arm capture and haulback test results indicated that the retraction of the arms in a 1 G field could be safely performed in 55 milliseconds with retraction strap lengths of 0.6 m. The maximum retraction strap force measured was 894 N recorded in a "Front" position test at a retraction strap velocity of 7.8 m/s. Selected parameters from retraction tests at the most severe test conditions are presented in Table 1. Eleven retractions were performed at these conditions and 61 retractions were accomplished in total.

One experimental condition purposely did not reproduce an operational retraction. In the laboratory tests, the NAR was fastened to the retracting cable with the piston fully retracted and adjusted for comfort. This assured that no significant afterload would be placed on the subject by the hydraulics after retraction. This would not be true during actual ejection. The terminal ring of the fully deployed NAR would be at the snubber preventing afterloads produced by excessive retraction. It is anticipated that the forces would continue to increase in the retracting straps during the ejection sequence, but this increase would be due to aerodynamic and inertial loading and not from the NAR deployment.

The protective padding was probably unnecessary even at the highest test levels. All subjects reported the experimental retractions as benign.

The arm capture and haulback tests demonstrated the NAR's ability to restrain and capture the arms regardless of the initial position. Rapid deployment and distributed force loading were demonstrated. In addition, all subjects were accommodated by a single garment without adjustment to sleeve or strap length.

Laboratory tests have shown the strengths of the NAR design and its potential for reducing windblast injuries to the upper limbs. It is currently a candidate in a program to provide a limb restraint system for the ACES II ejection seat.

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2. Specker, L. J., Jennings, T. J., Connors, M.P., Simple Nonrestrictive Arm Restraint System, U. S. Patent Application, October 1982.
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TABLE 1. SELECTED RETRACTION TEST PARAMETERS*

INITIAL POSITION	STRAP VELOCITY (m/s) RIGHT	STRAP VELOCITY (m/s) LEFT	PEAK FORCES (N) RIGHT	PEAK FORCES (N) LEFT	RETRACTION STRAP LENGTH (m) RIGHT	RETRACTION STRAP LENGTH (m) LEFT
D-Ring	7.5 (-)	11.0 (-)	431 (-)	516 (-)	0.58 (-)	0.62 (-)
Front	9.5 (0.9)	9.4 (1.0)	583 (62)	627 (13)	0.58 (0.03)	0.59 (0.04)
Across	9.9 (0.5)	10.2 (0.03)	641 (41)	658 (44)	0.56 (0.06)	0.61 (0.02)
Above	9.4 (-)	9.4 (-)	649 (-)	649 (-)	0.56 (-)	0.60 (-)
Side	9.4 (0.4)	9.4 (0)	694 (28)	707 (9)	0.63 (0.01)	0.64 (0.03)

*TABULATED VALUES ARE EXPERIMENTAL MEANS WITH THE STANDARD DEVIATION IN PARENTHESIS (DATA WERE COLLECTED AT 6.9 X 10^3 N/m^2 PSI·WITH 2 PISTONS, 4 PULLEYS/PISTON)